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Analyzing C2 Greyhound Capacity at Fleet Readiness Center Southwest (FRC SW)

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June 2009

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13. ABSTRACT (maximum 200 words)

In an effort to foster process improvement and ensure cost-wise support of the ongoing military operations throughout the world, Fleet Readiness Center Southwest (FRC SW) created its Continuous Process Improvement (CPI) as a vehicle to establish cost-wise readiness throughout its organization. The goal of this MBA project is to determine a reasonable range of production at Fleet Readiness Center Southwest (FRC SW) while attempting to maximize flexibility to support the fleet. The success of our project depended on to conducting capacity measurement analysis to support our findings and recommendations in assisting FRC SW. We used several modeling tools to assess capacity, which assisted in locating some of the constraints on the C2 production line at FRC SW. We found that the scope of the C2 production line requires further capacity analysis using tools beyond our project. We concluded our project with a recommendation for future research using modeling and simulation.

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ANALYZING C2 GREYHOUND CAPACITY AT FLEET READINESS CENTER SOUTHWEST (FRC SW)

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Submitted in partial fulfillment of the requirements for the degree of

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ABSTRACT

In an effort to foster process improvement and ensure cost-wise support of the ongoing military operations throughout the world, Fleet Readiness Center Southwest (FRC SW) created its Continuous Process Improvement (CPI) as a vehicle to establish cost-wise readiness throughout its organization. The goal of this MBA project is to determine a reasonable range of production at Fleet Readiness Center Southwest (FRC SW) while attempting to maximize flexibility to support the fleet. The success of our project depended on conducting capacity measurement analysis to support our findings and recommendations in assisting FRC SW. We used several modeling tools to assess capacity, which assisted in locating some of the constraints on the C2 production line at FRC SW. We found that the scope of the C2 production line requires further capacity analysis using tools beyond our project. We concluded our project with a recommendation for future research using modeling and simulation.

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LIST OF ACRONYMS AND ABBREVIATIONS

AIMD	Aviation Intermediate Maintenance Departments
ALSS	Aviation Life Support System
APH	Annual Paid Hours
ASI	Aircraft Systems Inspector: An Artisan who performs Test line Phase operations and maintenance tasking on aircraft including operational checks and procedures to make aircraft safe for flight.
ASR	Assembly Service Record
ASSY	Assembly
A&T	Acceptance and Transfer: Performs AIR Inventory and removes and stores loose gear at Test Line.
AVGFE	Aviation Gas Free Engineer: Technician assigned to test aircraft fuel cell for proper fume levels for the safety of personnel.
BRAC	Base Realignment and Closure
CPI	Continuous Process Improvement
DISSY	Disassembly
DLH	Direct Labor Hours
E&E	Examination and Evaluation or Examiner and Evaluator: Assigned by the PMTO to examine and evaluate the aircraft for proper material condition.
EHR	Equipment History Record
FCF	Functional Check Flight
FOD	Foreign Object Damage
FRC	Fleet Readiness Center
FRCSW	Fleet Readiness Center Southwest
ISO 9001	International Organization for Standardization
MOD	Modification
MRT	Mission Readiness Team
NADEP	Naval Air Depot
NAE	Naval Aviation Enterprise
NAVRIIP	Naval Aviation Readiness Integrated Improvement Program
NDI	Non-Destructive Inspection
NWC	Naval Working Capital
O&A	Over and Above report. Items that are found to require repair that is not part of the normal rework are considered Over and Above.
PAR	Performance Aircraft Representative maintains the E2/C2 work book data bases to ensure all required changes have been made to reflect corrections, additions or deletions in accordance with the PMI, SLEP, and Rewire specifications and production personnel.
PMI	Planned Maintenance Interval
PMI3	Periodic Maintenance Interval Three
RPR	Repair

SDLM	Standard Depot Level Maintenance
SLEP	Service Life Extension Life Program: The restoration/replacement of a primary aircraft structure that has reached its life limit.
SOP	Standard Operating Procedure
SRC	Scheduled Removal Component
TD	TECHNICAL DIRECTIVE - A document authorized and issued by COMNAVAIRSYSCOM to provide technical information necessary to properly and systematically inspect or alter the configuration of aircraft, engines, systems, or equipment subsequent to establishment of each respective baseline configuration. TDs include all types of changes and bulletins and consist of information that cannot be disseminated satisfactorily by revisions to technical manuals. NATEC controls assignment of TD numbers.
VIDS/MAF	Visual Information Display System/Maintenance Action Form
W&B	Weight and Balance
WBS	Work Breakdown Structure
WLS	Work Load Standard

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I. INTRODUCTION

A. FRC SW BACKGROUND

> The 2005 Base Realignment and Closure (BRAC) decision mandated that the Navy realign its three major aviation depots and 11 aviation intermediate maintenance departments (AIMD) into six regional maintenance centers. In October 2006, AIMDs at North Island, Point Mugu, Miramar, Pendleton, Yuma, and Kaneohe Bay merged with the Naval Aviation Depot at North Island, to create FRC SW. (FRC SW, 2009)

> FRC SW is the largest naval aircraft repair facility on the West Coast that specializes in intermediate and depot level support of Navy and Marine Corps aircraft and related systems. (FRC SW, 2009) Prior to 2001, Naval Aviation was fragmented into several 'stove pipes' of operations (operations, maintenance, and development) with each functional area managing its own interests and lack of coordination among operations. The lack of coordination caused the Navy to lose money at a high rate, which necessitated an extensive reevaluation of how the U.S. Navy conducted business. (FRC SW, Command Overview, 2008)

The FRC SW mandate is to perform competitively with the industry in an active effort to provide the best value to taxpayers.

> As such, FRC SW operates on a Navy Working Capital (NWC) fund. Therefore, the command recoups money from the operational forces by "selling" products and services back to the Navy. Money received from selling those products goes to covering the command's overhead and operational costs. (FRC SW, Command Overview, 2008)

Other commands in the Navy are given funds and told to go forth and spend by budgeting wisely. FRC SW is essentially a company with a goal to earn enough money to break even, covering all costs including capital equipment.

According to FRC SW's command brief and staff comments, FRC SW provides worldwide support in times of both peace and conflict.

In times of peace:

- The command competes directly in the industry by providing repair and maintenance support to the fleet at a competitive price, thus keeping maintenance costs down (Markle, FRC SW Fares Well in World-Class Competition, 2009).
- "The Navy still operates numerous aircraft that are no longer in production but are still required to maintain operational readiness. The maintenance of these aircrafts generally does not present profitability to industry. Private industry will bid on jobs that provide profitability and pass on the jobs that do not. Therefore, FRC SW performs the required maintenance and repair. For example:
    - *Industry may incur a large overhead and startup cost to manufacture an obsolete part that is still being used by the Navy. However, FRC SW can manufacture the same part at a lower cost."* (FRC SW, Command Overview, 2008) (NAVAIR, 2009)

In times of conflict:

- FRC SW is a force multiplier, meaning that they make our armed forces more effective with advantages such as on-site artisans and flexibility in sending artisans to areas of conflict for rapid response maintenance. Therefore, damaged aircraft can return to combat sooner. This dramatically increases FRC SW's ability to compete in the industry while increasing the capability of our armed forces. (Markle, FRC SW Site MCAS Miramar: Ready to Repair on a Moment's Notice, 2009)

In both times of peace and conflict:

- The command works with the same unions found in the industry; however, the FRC SW unions represent a non-striking workforce. Therefore, FRC has a more reliable workforce compared to the industry. (FRC SW, Command Overview, 2008)

- All services provided by FRC require no contract. Any work performed by industry requires "contracts" that spell out specific services and products to be supplied.

FRC SW is a major player of the Naval Aviation Enterprise (NAE) cost-wise readiness initiative. The NAE was created to enable communication across all elements of the enterprise and nurture process improvement to ensure cost-wise support of the ongoing military operations throughout the world. Cost reduction is an ongoing process. Our project is a contribution to the ongoing effort. Continually conducting analysis of FRC SW's production (repair, process, capacity, and overhead cost) is also a contribution to the ongoing process improvement goal of NAE.

B. C-2 BACKGROUND

As a full service repair facility, FRC SW engages in maintenance and repair of eight different Navy and Marine Corps Aircraft and their associated components. Those Aircraft include the F/A-18 Hornet Fighter/Attack Aircraft, E-2 Hawkeye early warning aircraft, C-2 Greyhound cargo plane, AV-8 Harrier Attack Jet, H-60 Seahawk Helicopter, H-53 Super Stallion heavy-lift helicopter, UH-1 Huey utility helicopter, and the AH-1 Cobra attack helicopter. FRC SW is capable of repairing over 95 percent of each aircraft's components, and has the capability to manufacture needed parts.

Due to the complexity and extent of FRC SW's total aircraft production line, we were tasked with only a small portion for analysis. FRC SW requested a capacity analysis of the C2 production line, specifically, an analysis of the Planned Maintenance Interval Three (PMI3) line. The C-2 is the Navy's only carrier-based cargo aircraft that ferries parts, supplies, and personnel to the ship while at sea. The C-2 production line is shared with the E-2 Hawkeye. E-2/C-2 production line is known as a "single piece flow" line. Figure 1 demonstrates the shared resources of the aircrafts at the disassembly cell before separating into their respective production line in a single flow process. The current workload for the C-2 is six aircraft per year at 330 days of work per aircraft (6 cell production phase x 55 days per cell).

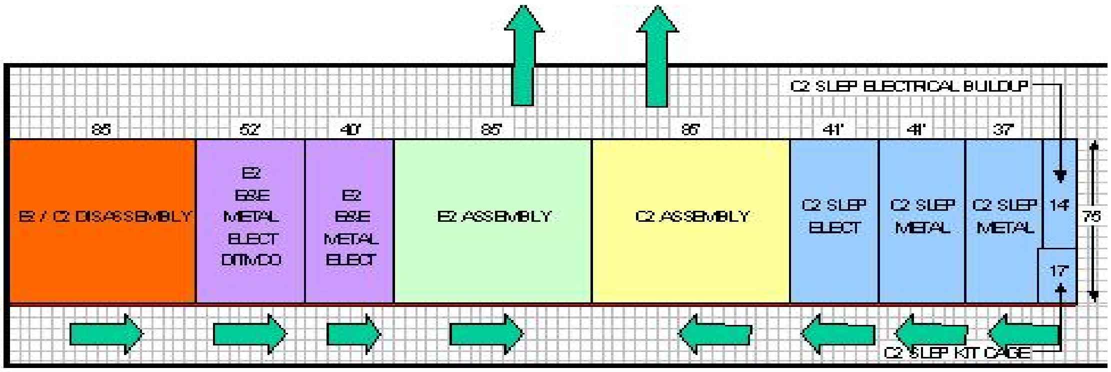

Figure 1. E2/C2 Single Flow Process (from FRC SW, 2009)

C. RESEARCH OBJECTIVES

The objective of this research project is to conduct an analysis of capacity in the C2 production line at FRC SW. Our analysis will help FRC SW determine a viable range of C2 production that will reduce cost while effectively maintain flexibility in supporting the fleet. To achieve our objectives, we developed a process flow chart, precedence diagram and a work breakdown structure model of the C2 production line. The flow charts and diagrams represent data collected from the C2 Standard Operating Procedure (SOP), PMI3 specifications, and site visits. Although this project focuses on the C2, it overlaps other FRC SW processes due to shared resources that are discussed in later chapters.

D. RESEARCH QUESTIONS

The primary question to be addressed by this project is: What is the current C2 PMI3 production capacity? Other relevant questions to our project are:

1. What range of production (maintenance) can FRC SW support?
2. If FRC SW needs to increase capacity, what changes in the production line would be recommended?
3. What are the bottleneck(s) and/or constraint(s) in the C2 production line?

E. METHODOLOGY

The methodology applied in this research project consisted of the following steps:

1. Literature review was conducted as a first step. The literature review assisted in identifying the reference material we would require to support the objective of the project. It also assisted in narrowing the scope of this project.
2. Site visits were conducted to collect necessary data for analysis. During the site visits, E2/C2 PMI3 and SOP data were provided by FRC SW staff, which allowed us to familiarize ourselves with the production process.
3. After gaining familiarity with the production line of the C2, we created three operations management models: a Process Flow Chart, a Precedence Diagram, and a Work Breakdown Structure (WBS) to help us conduct our capacity analysis. .
4. We then conducted a data analysis of the various models to draw a conclusion and provide recommendations to improve capacity.

The rest of this report is organized as follows; Chapter II discusses the modeling methodology and tools utilized throughout our project to assist in addressing capacity at FRC SW. In Chapter III, we present the details to C2 PMI3 through a process flow chart, precedence diagram and a WBS. Chapter IV provides our data analysis. In Chapter V we present our conclusion and recommendations.

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II. MODELING METHODOLOGY AND TOOLS

The purpose of this chapter is to highlight the process improvement and modeling tools we found relevant and which assisted us in creating our models to address capacity at FRC SW. This analytical model review draws on the work of Eliyahu Godratt introduction to the *Theory of Constraints*, previous research by Kang and Apte regarding *Lean Six Sigma*, Richard Chase, F. Robert Jacobs and Nicholas J. Aquilano's *Operations Management for Competitive Advantage*, FRC SW internal documents (E2/C2 production line SOP), and Thomas Klammer's *Capacity Measurement and Improvement guide to evaluating and optimizing capacity productivity.*

A. METHODOLOGY

In the early 2000s, Navy leadership recognized the importance of finding and improving processes across the enterprise by replacing inefficiency. The Navy recognized that the improvement of inefficient processes can yield monetary savings as well as improve readiness levels. NAE and FRC SW devised a continuous process improvement (CPI) program, incorporating the best business practices of several CPI programs, including Theory of Constraints, Lean, and Six Sigma. Figure 2 depicts the elements of these principles, which join to create the AIRSpeed Toolset practiced at FRC SW. (FRC SW, Command Overview, 2008)

Figure 2. AIRSpeed Toolset (from FRC SW, 2009)

AIRSpeed became the Naval Aviation Readiness Integrated Improvement Program (NAVRIIP) vehicle for cost-wise readiness throughout NAE. It establishes the planning, training, integration, sustainment, and monitoring of business practices throughout NAE. (FRC SW SOP, 2009) (FRC SW SOP, 2009) Our project ties into the AirSpeed effort by focusing on capacity to address the Theory of Constraints part of the AirSpeed methodology.

B. ELEMENTS OF AIRSPEED

The *Theory of Constraints (TOC)* was popularized by Eli Goldratt in his book titled *The Goal (1984)*. The theory of constraints has a fundamental thesis that a few constraints determine the performance of any system. Goldratt advocates managers to focus on constraints rather than product costs. The plant management approach advocated by the book is based on the premise of thinking of your plant as a machine through which product flows. Your job is to overhaul the machine to maximize its throughput, minimize the building of pressure (inventory) within it, and minimize the cost (operational expense) of running it (Goldratt, 1984).

The second major component of Airspeed is its incorporation of *Lean,* a process improvement technique popularized by James Womack in his book titled *Lean Thinking, 1996.* The Lean process helps organization determine value and eliminate *Muda*, or waste, and promotes continuous process improvement. The core of the Lean Thinking is the determination of value using *value-stream mapping*. Lean methodology can be summarized as (Kang & Apte, 2006):

- Focusing on maximizing process velocity,
- Providing tools for analyzing process flow and delay times at each activity in a process,
- Emphasizing Value-stream Mapping which centers on the separation of “value-added” from “non-value-added” work with tools to eliminate the root causes of non-valued activities and the associated cost,

- Recognizing and attempting to eliminate eight types of waste/non-value-added work: defects, inventory, overproduction, waiting time, motion, transportation, processing, and human talent, and
- Creating workplace organization through the *Five S* methodology consisting of sort, straighten, sustain, sweep, and standardize.

The third major component of Airspeed is Six Sigma. The Six Sigma process seeks to improve customer satisfaction by reducing and eliminating defects. Six Sigma originated in 1986 at Motorola in an attempt to improve manufacturing processes (Kang & Apte, 2006). Six Sigma can be summarized as (Kang & Apte, 2006):

- Emphasizing the need to recognize opportunities and eliminate defects as defined by customers,
- Recognizing that process variation hinders our ability to reliably deliver high-quality services,
- Requiring data-driven decisions and incorporating a comprehensive set of quality tools under a powerful framework for effective problem solving and providing a highly prescriptive cultural infrastructure effective in obtaining sustainable results.

C. TYPES OF CAPACITY

Thomas Klammer's *Capacity Measurement and Improvement* provides a practical understanding of capacity. He reiterates that in a competitive economy, the effective use of capacity is vital. Klammer's capacity model in Figure 3 shows the relationship of the three major capacity measurements (Klammer, 1996). This project identifies the idle, non-productive, and productive capacity in the C2 production line that is addressed in later chapters. By identifying the various types of capacity, we were able to provide recommendations to assist FRC SW in improving productivity at existing capacity.

The capacities from Figure 3 are defined as the following:

- Idle Capacity is broken into capacity that is 1.) unused but usable and 2.) unused and not usable. Examples of unused but usable idle capacities are delay in a

production line, financial constraints, and/or distribution constraints. Examples of unused and not usable capacity may be product obsolescence (upgrades) that are unavailable for use. Other examples of unused and not usable are administrative constraints caused by government regulations (downtime from federal holidays), management policy, or contractual arrangements. Therefore, management may approach idle capacity by assessing if the idle capacity is an opportunity to convert it into productive capacity or to abandon the idle capacity.

- "Non-productive capacity includes setups, standby, maintenance, downtime, rework, and scrap." Non-productive capacity can be summarized as time and money that results in capacity usage but are not directly producing "good products."

- Productive capacity gives value to customers by the production of "good products." Productive capacity includes for example: cutting, molding, welding, painting, and assembly. According to Klammer, productive capacity is the most desirable by managers (Klammer, 1996).

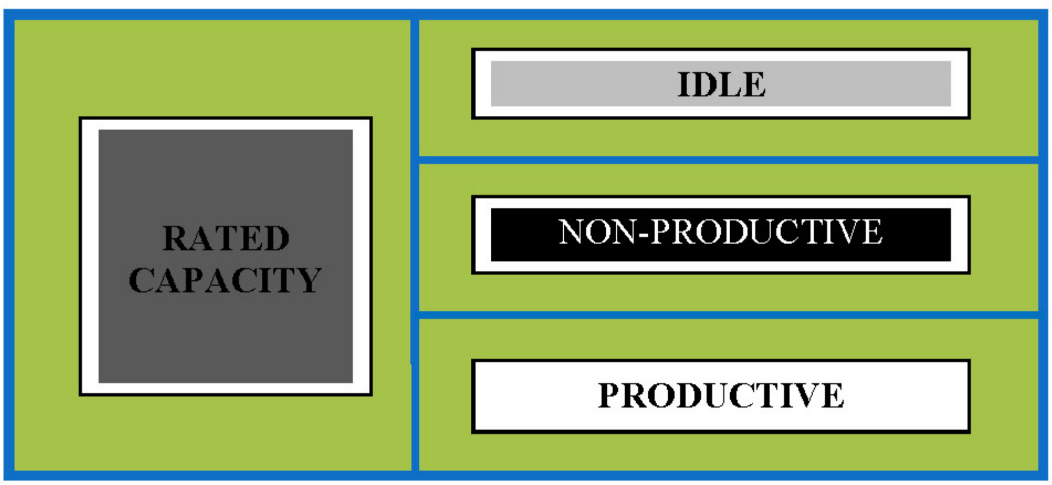

Figure 3. Klammer's Summary Capacity (from Klammer, 1996)

D. PROCESS ANALYSIS

According to Chase, Jacobs, and Aquilano, process analysis is a tool used to bring an organized picture to the steps in a process. In seeking to identify the capacity of the C2 shop, we had to first understand that what goes into the production line is what must come out. We also had to understand the characteristics of the process. For example:

If you pour water into a funnel, the outlet of that funnel will limit the amount of water that can flow through it. You can also determine at what rate water is limited. If water is poured into the funnel at a rate greater than the outlet, you may be left with water overflowing the funnel. The overflowing water represents waste, which is a nonproductive use of capacity. Additionally, adding water to an overflowing funnel is essentially increasing the time it would take the water to flow through the funnel (Richard B. Chase, 2006). Our project identifies what, in the C2 production line, is limiting output.

A process flowchart denotes what happens to the product as it progresses through the production facility. In this case, the product is the C2 aircraft. According to Chase, Jacobs, and Aquilano, understanding how processes work is essential to ensuring the competitiveness of a company. This project, in and of itself, is not a process analysis project, but we use process flow chart to help us better understand the C2 product processes, and help us build the WBS.

The precedence diagram shows the logical relationships between the tasks identified in the process flow chart. The precedence diagram shows the actual constraints underlying the process flow. Tasks are identified, as well as dependencies. Chase, Jacobs, and Aquilano address splitting tasks. The splitting of tasks enabled us to capture and analyze the tasks that may be placed in parallel, further defining dependencies. We used a precedence list and diagram to help us identify those tasks. Capacity or time may gain an advantage if task can be placed into parallel.

The WBS shows a breakdown of tasks/phases through subtasks. For the purpose of this project, we show the WBS through phases. Chase, Jacobs and Aquilano describe this tool as breaking down a project into manageable pieces. Levels may vary but responsibility and accountability is defined. The overall concept is to identify the

hierarchical structure of the C2 production in an organized way. Because the number of levels in a WBS will vary depending on the project, for our project the level of detail is the level at which the organizations can be assigned responsibility and accountability for accomplishing the work package.

III. C2 PMI3 PROCESS DETAILS AND MODELS

The purpose of this chapter is to provide an overview of the process flow of the C2 PMI3. We also provide a detailed description of the precedence diagram followed by a description of the work breakdown structure. Additionally, we discuss the factors that support the validity of the data collected, as well as how the data was analyzed.

The PMI3 handbook by NAVAIR is the overview and basis for the process flow chart, precedence diagram, and WBS. However, the FRC SW SOP approved by the E2/C2 production managers outline the production procedure for each phase (FRC SW, 2009).

According to the SOP, the aircraft are first inducted at the Test Line (TL) and then transferred for completion of the Cell Based Single Piece Flow Lean/AirSpeed Product line before returning to the TL before final delivery to the customer. The SOP handbook further defines the responsibilities of different managers, supervisors, and artisans in regards to their roles in the AirSpeed process. The area of responsibilities are even more defined and separated by phases as demonstrated in the WBS, which is presented in Figure 8 in Chapter V.

In essence, the SOP is used as the quality management system for the E2/C2 production line. It is a living document that can and does change to drive improvement without loss of effectiveness within the organization (NAVAIR PMI3, 2006).

A. BACKGROUND DESCRIPTION

There are a variety of Planned Maintenance Interval (PMI) programs utilized by the Naval Air Systems Command to support the scheduled planned maintenance interval concept. PMI programs provide for airframe systems and component inspection, defect correction, preventative maintenance, modification and Technical Directive (TD) compliance. The PMI requirements for aircraft subject to this process are the minimum requirements. The requirements are formulated and established to the depth required to ensure reliability and operational availability of the aircraft. However, the requirements

must ensure reliability and operational availability at a minimum cost for the duration of the established service period and provide intermediate support of total service life. Based on the PMI Specification, the PMI requirements include, but are not limited to:

- A thorough and comprehensive inspection of selected aircraft structure and flight critical components by visual and appropriate Non-Destructive Inspection (NDI) methods with repair as required ensuring the serviceability of the affected structure or components until the next PMI induction (FRC SW, 2009).
- Compliance with all approved technical directives (TD) with the exception of authorized deviations.
- Replacement of depot replaceable life/time/event limited components or parts, which will exceed the specified replacement intervals prior to the next scheduled PMI (NAVAIR PMI3, 2006).

The PMI3 process starts before the aircraft is transferred to FRC SW. The activity in possession of the aircraft and has aircraft status reporting requirement to higher echelon is considered the *reporting custodian*. Prior to the arrival of the C2 aircraft for PMI3, the reporting custodian performs a pre-induction evaluation. The evaluation is conducted to provide early identification of the aircraft configuration and material condition. Thirty days prior to induction, the activity in possession of the aircraft sends the relevant equipment history records to FRC SW. The activity also performs an aircraft functional check flight (FCF), with FRC SW representative if available in anticipation of the ferry flight. An inspection of engine compressors and propeller is performed. All discrepancies that can be corrected by organizational (O) and intermediate (I) level maintenance are corrected. Essentially, aircraft delivered to FRC SW for PMI3 has to be in an approved configuration and operational.

The Planned Maintenance Interval (PMI) maintenance process is conducted with an approved work load standards (WLS) based on PMI specification, which details the engineering and processing requirements to perform scheduled depot inspection and repair maintenance on aircraft, engines, major components, or support equipment (NAVAIR PMI3, 2006).

B. ORGANIZATION OF THE MODELS

We developed three models to describe the C2 production line and provide data for the analysis. The models were developed using data from the PMI3 manual, FRC SW SOP, FRC SW staff, and site visits. The Process Flow Chart was the initial model utilized followed by the Precedence List/Diagram and the WBS. The three models were dependent on each other, which enabled a more thorough analysis of the collected data. The three related models enabled us to perform capacity analysis, which assisted us in our conclusions and recommendations.

C. DEVELOPMENT MODEL

1. Process Flow Chart

We initiated a process flow chart to understand how the production line of the C2 aircraft is carried out and to match the research objectives with our data analysis. Figure 4 depicts the step-by-step representation of each phase to overall production. The research called for a step-by-step representation of the C2 PMI production line process in order to conduct an analysis to define capacity measurement and its area of improvement.

By conveying the phases to a step-by-step picture, we then were able to take each phase and understand its relationship to the overall production line. Because there is flexibility built into the processes, and the object of the project was to analyze capacity, the process flow chart serves to provide a broad process view and may not truly reflect the detail of the processes. A description of the process flow chart is below. We use the section headings introduced here to tie in the work breakdown structure with the process flow.

a. Pre-Induction

As we discussed previously, the pre-induction process starts well before the aircraft arrives at FRC SW. The reporting custodian conducts a pre-induction evaluation to provide early identification of the aircraft configuration and material condition. The aircraft Miscellaneous History Record, Scheduled Removal Component

(SRC) cards, Assembly Service Record (ASR), Equipment History Record (EHR) cards, and Technical Directives List 02 and 04 and Aircraft Inventory Record are sent from the squadron to FRC SW. The reporting custodian also performs a transfer inspection of the aircraft.

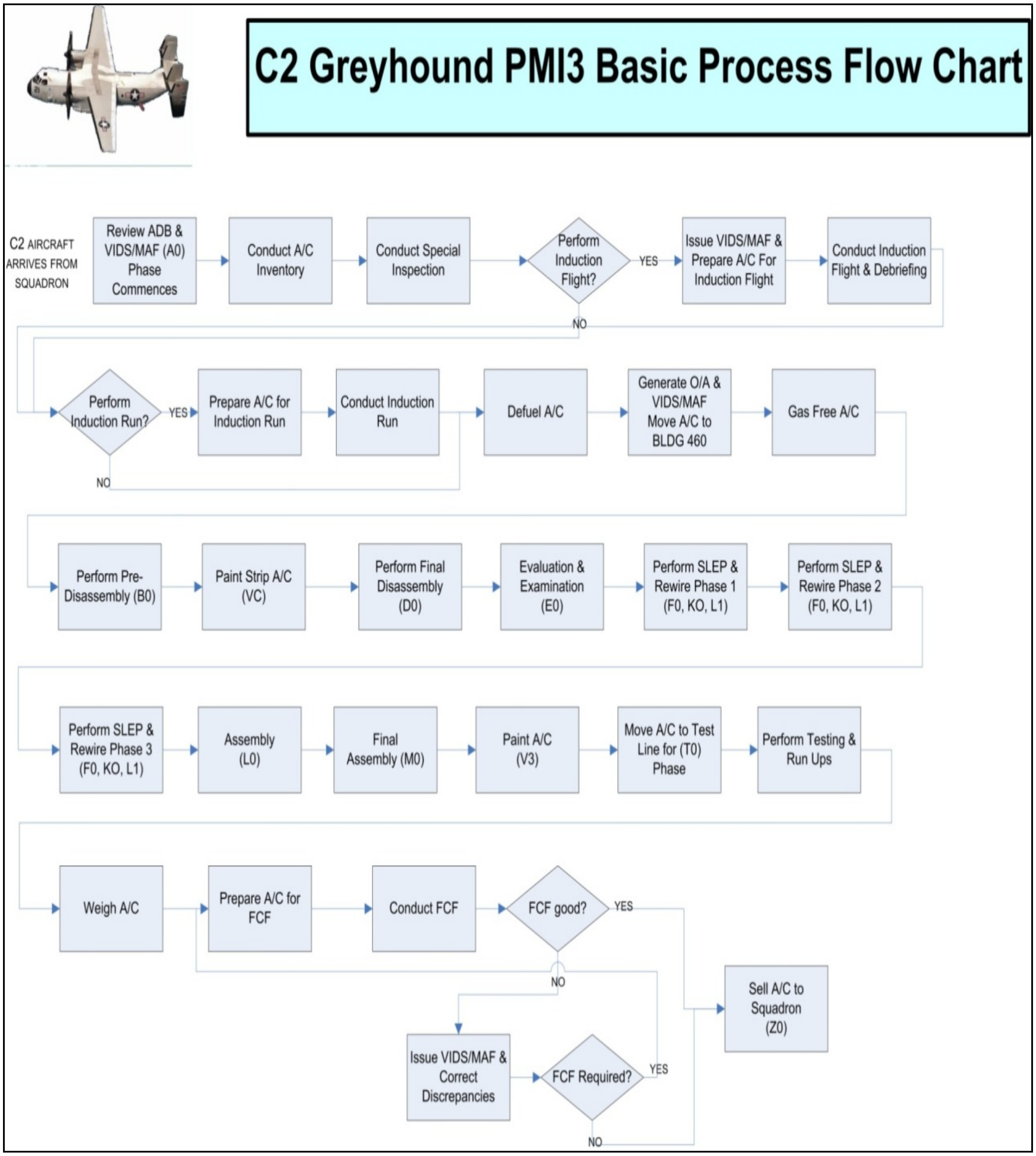

Figure 4. C2 Basic Process Flow Chart

A Function Check Flight (FCF) with participation by the FRC SW representative, if available, is conducted as part of the transfer inspection. During the FCF, the designated FRC SW representative attempts to perform system tests as per PMI Specification. Those systems not tested during the FCF will be tested at FRC SW. At this point, the aircraft is transferred to FRC SW and the flow shown in Figure 4 begins.

b. Induction (Ao) Phase

An inventory of the aircraft components is generally performed as soon as possible after receiving the aircraft. Any equipment found missing has to be requisitioned by the reporting custodian. Survival equipment is removed, stored, and maintained during PMI processing of the airframe. The equipment will be returned to the same aircraft at completion of the PMI process. Any loose equipment is tagged and stored. All records are reviewed and analyzed to help determine production planning. Technical directives requirement, high time components, engine components, and any special work requests from the squadron are reviewed.

The Aircraft Systems Inspector (ASI) performs the induction phase operational checks and maintenance actions in accordance with the Induction Phase workbooks and applicable directives. The aircraft is then prepared for an induction flight. After an induction flight, an induction run is performed. The upholstery is removed from the aircraft. In rare unplanned events such as engine foreign object damage (FOD) or other mechanical failure, the induction flight and the induction run may be waived. However, if the aircraft is flyable, an induction flight and a post flight debrief is performed.

After the induction flight debrief has been completed, induction runs are performed. The Examination and Evaluation (E&E) team leads the induction runs and control the direction and depth of troubleshooting. After the induction run, the aircraft is defueled and prepared to be moved to Building 460. At this time, Over and Above (O&A) and Visual Information Display System/Maintenance Action Form (VIDS/MAF)s

of discrepancies found during testing are generated. Aviation Life Support System (ALSS) gears are removed and appropriate equipment are transferred to the ordnance shop.

Once the aircraft has been moved to building 460, all the fuel cells go through a gas free process. The fuel cells have to be certified by an Aviation Gas Free Engineer (AVGFE) before they can be worked on by maintenance personnel

c. Pre-disassembly (Bo) Phase

During the pre-disassembly phase, personnel perform a pre-disassembly inspection in accordance with the standard work sequence chart. The disassembly is usually to the level that is sufficiently to perform the inspection requirements of each module, required restoration, authorized modifications, and tests.

d. Strip (Vc) Phase

After the aircraft has completed the pre-disassembly phase it goes to the paint shop for paint stripping. At this time, the paint is stripped from the aircraft down to bare metal to allow for thorough inspection of the metal surfaces for defects, especially corrosions.

e. Disassembly (Do) Phase

Following the paint stripping, the aircraft goes through a final disassembly process. During final disassembly, personnel are to identify any obvious defect(s), specifically cracks, corrosion, damaged controls, worn hinges, attach fittings, bearings, bushings, and bolts, distortion and elongation of bolt holes, and any signs that may lead to disassembly to a greater depth than specified by requirements. Removed components that need to be repaired or overhauled are sent to appropriate section of FRC SW. If certain major parts are needed, the reporting custodian is informed to requisition replacement parts.

f. Examine and Evaluate (Eo) Phase

This phase of the PMI3 process requires the most involvement of the E&E team. With the aircraft disassembled, the E&E team is able to better examine and evaluate the condition of the aircraft and generate appropriate work documents to restore the aircraft to a condition that can be maintained at the organizational and intermediate maintenance activities.

g. Slep/Rewire

This step of the PMI3 process is where the bulk of the restoration work is performed. The Service Life Extension Program/Rewire (SLEP/REWIRE) process takes 165 days to complete and includes structural enhancements to allow the C2 to increase its operating service life from 15,020 landings and 10,000 flight hours to 36,000 landings and 10,000 flight hours(Navy, 2009). Proper condition of aircraft wiring is vital to safe operation and mission performance. All C2 aircraft gets completely rewired during PMI3.

h. Assembly (Lo/Mo) Phase

During the assembly phase, parts and components that have been sent to be repaired, overhauled, or placed in a storage locker are brought back for assembly. If parts are not all available the aircraft may be delayed here.

i. Paint (V3) Phase

After final assembly, the aircraft is moved to the paint shop for painting. Upon completion of a comprehensive painting process, the aircraft is then moved to the test line for final testing.

j. Mrt/Test Line (No/To) Phase

This is the last process the C2 goes through before delivery to the customer. The final processing includes:

- Compass calibration: Aircraft compass is calibrated and compensated.
- Hydraulic System: Hydraulic oil sample is collected and analyzed for contamination. If any contamination is detected, corrective actions is performed and sample recollected
- Inventory Equipment: Reinstall or replace with equivalent serviceable items, on the same BUNO aircraft, all inventory equipment removed during aircraft induction.
- Logs and Records: Aircraft inventory record is verified and reconciled to reflect actual items inside the aircraft. The relevant aircraft logbook is updated. Any pages purged are placed in a separate envelope to be given to the activity taking delivery of the aircraft.
- Power Plants: An engine performance check on each engine is performed and data is entered on the engine trend analysis plotting chart.
- Weight & Balance: Aircraft is weighted. The weight and balance documentation is updated.
- Servicing: After completion of specified maintenance requirements, the aircraft, drive components and engines are de-preserved and serviced.
- Operational Tests: Preflight, prestart, start, taxi, and run-up tests are conducted. Any critical or major defects discovered during the operation test are corrected and retested as required.

Once all corrections of critical and major defects discovered during the test flights have been corrected, the aircraft will be ready for delivery to the customer. The customer will accept the aircraft into their possession through transfer of appropriate documentations.

2. Precedence List and Diagram

The precedence list and diagram provide a means to help understand the dependencies of each task. Figure 5 depicts the precedence list that shows the

prioritization of the tasks. The prioritization of the tasks is the first step in creating the precedence diagram because it assists in identifying redundancy. The precedence diagram in Figure 6 shows a graphical depiction of the tasks in the C2 production line. It provides a visual representation of the relationship between dependent and non-dependent tasks. Figure 5 and 6 also provide the opportunity to verify each phase in the process flow chart. For example, each phase from the process flow chart have multiple tasks. We followed the tasks through the precedence list and diagram to differentiate parallel and sequential tasks. An example of a parallel task is task I *(Generate over and above documents and VIDS/MAF);* this task may be performed in parallel with task E through L. The sequential part of both the list (Figure 5) and the diagram (Figure 6) shows what has to be completed first before the next step can be accomplished. For example, task M (*Perform pre-disassembly phase (BO))* cannot be completed until the aircraft is gas free (Task L).

Though the basic flow chart shows sequential dependencies between steps, some processes may be able to be performed in parallel. An example is to conduct an A/C inventory (Task C) while conducting a special inspection (Task D) at the same time. Identifying what may be performed in parallel allows for some flexibility in the process flow.

C2 PMI3 PRECEDENCE LIST

Task	Description	Tasks That Must Precede
A	C2 aircraft arrives from squadron	-
B	Review ADB and VIDS/MAFs (A0) phase	A
C	Conduct aircraft inventory	B
D	Conduct aircraft special inspection	A
E	Issue VIDS/MAF & prepare aircraft for induction	C and D
F	Conduct induction flight and debrief	E
G	Prepare aircraft for an induction run	C
H	Conduct an induction run & debrief	G
I	Generate over and above documents and VIDS/MAF	D
J	Defuel gas free aircraft	F or H
K	Move aircraft to building 460	J
L	Gas free aircraft	K
M	Perform pre-disassembly phase (B0)	L
N	Paint strip aircraft (VC)	M
O	Perform final disassembly (D0)	N
P	Perform Evaluation & Examination (E0)	O
Q	Perform SLEP and rewire phase 1 (F0, K0, L1)	P
R	Perform SLEP and rewire phase 2 (F0, K0, L1)	Q
S	Perform SLEP and rewire phase 3 (F0, K0, L1)	R
T	Perform assembly (L0)	S
U	Perform final assembly (M0)	T
V	Paint aircraft (V3)	U
W	Move aircraft to test line for (T0) phase	V
X	Perform testing and run ups	W
Y	Prepare aircraft for FCF	X
Z	Conduct FCF	Y
AA	Sell aircraft to squadron (Z0)	Z

Figure 5. C2 PMI3 Precedence List

C2 PMI3 PRECEDENCE DIAGRAM

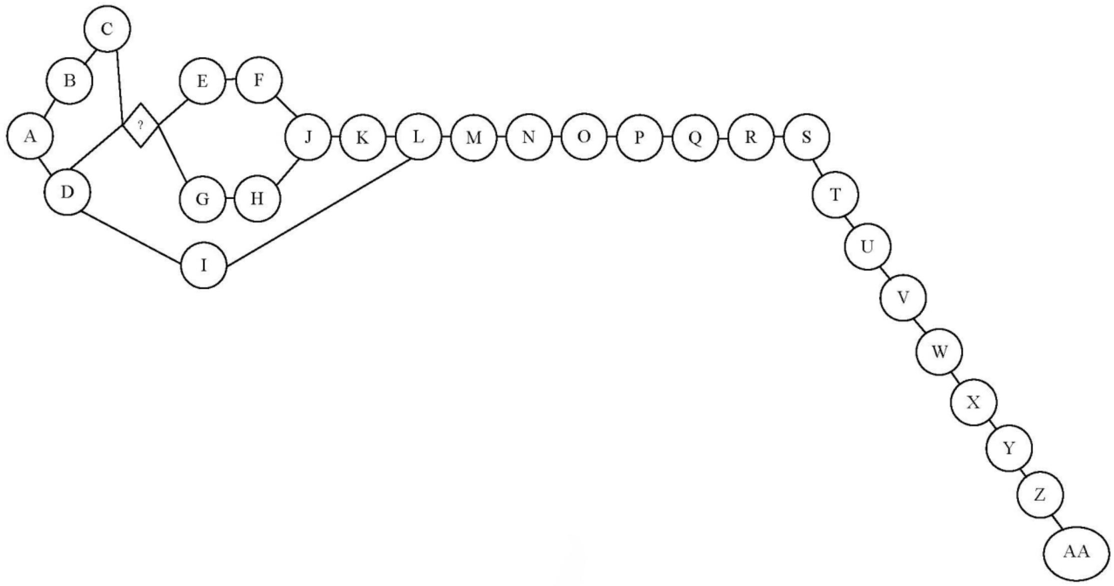

Figure 6. C2 PMI3 Precedence Diagram

3. Work Breakdown Structure (WBS)

The WBS is a comprehensive classification of the PMI process broken down in phases (Figure 7). Each phase lists the required resources by trade and hours required for those resources. For instance, in the Induction (AO) Phase 96 hours of work is required from the *DISSY/RPR/MOD/ASSY – MECHANIC* resource. The hours and resources listed are based on an approved Work Load Standard (WLS) hours. Standard is based on eight-hour days, with an abbreviated second shift to maintain continuity on lead aircraft. In order to execute the workload, there is overtime (OT) including Saturdays, but common practice is no production work is scheduled on federal holidays. According to C2 staff, OT is mostly the result of fleet requirements and disruption caused by not receiving material on time and subsequent requirement of the extra attention once the material is available.

The WBS is a structure that involves 18 major resource pools working 14 phases of the PMI3 process. Some WLS resources are particular to only one phase of work, while others such as *E&E* are distributed across a broader range of phases. The WBS (Figure 7) shows 17,437 required resource hours to complete one C2 aircraft. In practice, FRC SW has been able to complete work in a shorter amount of time than that allowed by the standard. This difference between the standard and the historical performance of FRC SW is discussed in Chapter IV.

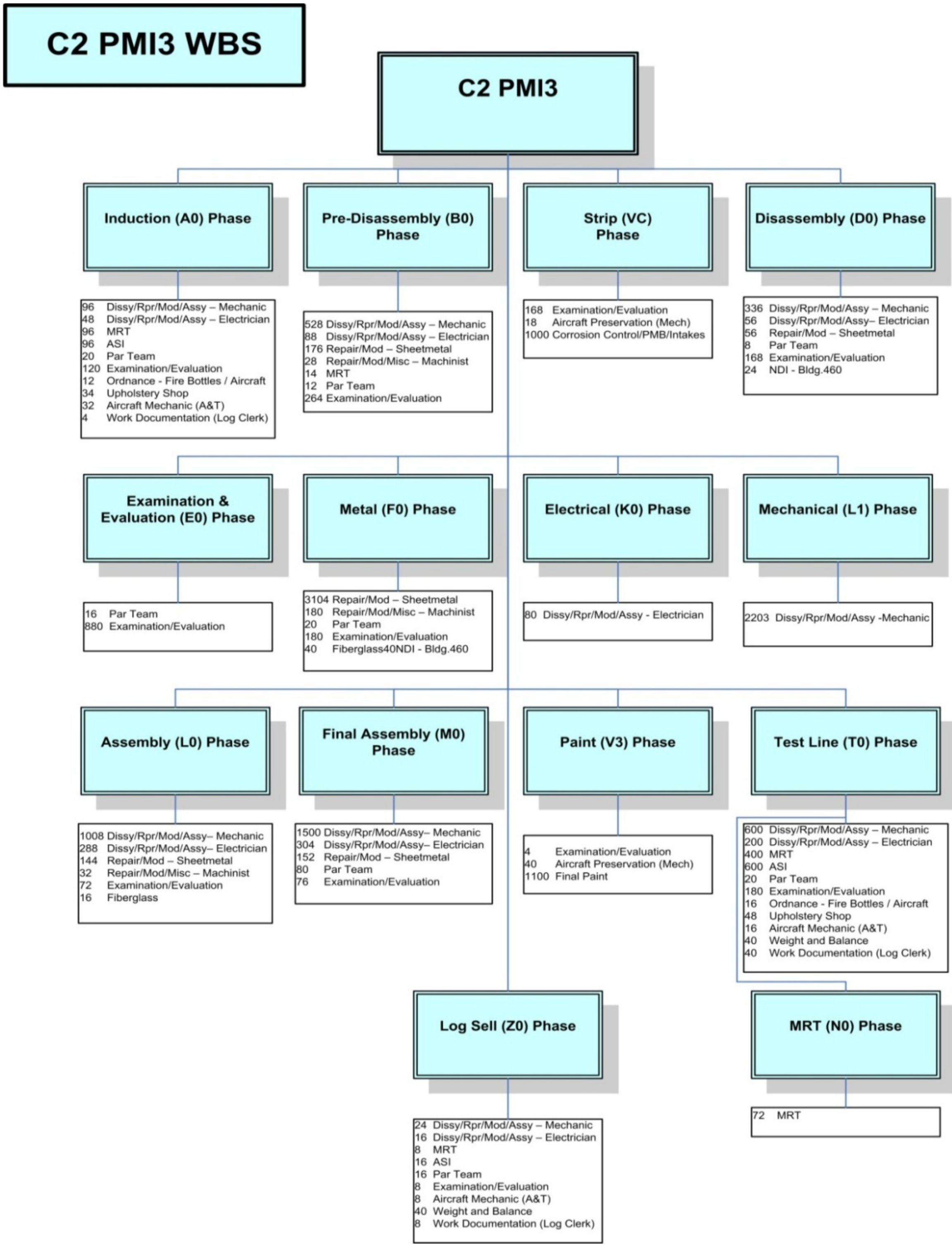

Figure 7. C2 Work Breakdown Structure (WBS)

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IV. DATA ANALYSIS

In this chapter, we present our findings from the data collected during this project. We also provide the background for our recommendations and areas of consideration for future research.

A. INITIAL CAPACITY ANALYSIS

FRC SW completed six C2s under the PMI3 program in Fiscal Year 2008 (FY08) and plans to complete six C2s in FY09 (FRC SW). Based on data we gathered from site visits and from the E2/C2 planning supervisor we populated the WBS and Table 1 for numerical analysis. In the table, identical resources from the WBS were consolidated to facilitate analysis to determine the current capacity of the C2 production line. Some of the resources are shared between the E2 and C2 aircraft and some are shared among the other types of aircraft in FRC SW's production lines.

Descriptions of Table 1 columns are as follow:

Column 1 lists the resources required to complete one C2 PMI3. The resources were consolidated from the WBS (Figure 6). Column 2 lists the number of personnel identified by FRC SW as part of the Column 1 resources.

According to FRC SW staff and C2 production managers, FRC SW utilizes 6.2 Direct Labor Hour (DLH) in an eight-hour workday, which equates to approximately 1,615 DLH per year. FRC SW staff finds that in some cases they achieve 1,686 DLH, which would give them slightly more capacity. However, the Office of the Deputy Under Secretary of Defense for Logistics and Materiel Readiness publishes DoD publication 4151.28H, which mandates the use of 1,615 DLH (Deputy Under Secretary of Defense, 2007).

The calculation of 1,615 DLH is derived by using the following formula: (2,080 APHs – 80 hrs Holidays – 274 hrs Leave – 111 hrs Indirect) = 1,615 DLH (Annual Productive Hours) (DoD 4151.18-H, 2007). For consistency purposes, we utilized 1,615 APH for capacity analysis throughout this project.

1	2	3	4	5	6	7	8
RESOURCE	**# of Personnel**	**Total Hours Available**	**Work Load Standard (WLS) Hours Required Per C2**	**Annual C2 Capacity**	**Historical Estimate of Hr Spent per AC**	**Calculated Capacity Based on Historical Estimate Per AC Hr**	**Total Hr Must Have Spent Based on Historical Estimate & Efficiency**
Repair/Mod - Sheetmetal	6	9,690	3,632	2.67	3,232	3.0	19,395
Dissy/Rpr/Mod/Assy - Mechanic	11	17,765	6,295	2.82	5,603	3.2	33,615
ASI	2	3,230	712	4.54	634	5.1	3,802
MRT	2	3,230	590	5.47	525	6.2	3,151
Dissy/Rpr/Mod/Assy - Electrician	5	8,075	1,080	7.48	961	8.4	5,767
Examination/Evaluation	12	19,380	2,120	9.14	1,887	10.3	11,321
Repair/Mod/Misc - Machinist	2	3,230	240	13.46	214	15.1	1,282
Final Paint	10	16,150	1,100	14.68	979	16.5	5,874
Corrosion Control / PMB / Intakes	10	16,150	1,000	16.15	890	18.1	5,340
PAR Team	2	3,230	192	16.82	171	18.9	1,025
Upholstery Shop	1	1,615	82	19.70	73	22.1	438
NDI - Bldg.460	1	1,615	64	25.23	57	28.4	342
Aircraft Mechanic (A&T)	1	1,615	56	28.84	50	32.4	299
Fiberglass	1	1,615	56	28.84	50	32.4	299
Work Documentation (Log Clerk)	1	1,615	52	31.06	46	34.9	278
Weight and Balance	2	3,230	80	40.38	71	45.4	427
Ordnance - Fire Bottles / Aircraft	1	1,615	28	57.68	25	64.8	150
Aircraft Preservation (Mech)	3	4,845	58	83.53	52	93.9	310
TOTAL:		**117,895**	**17,437**		**15,519**		**93,114**
C2 Production Team Efficiency Rate	112.4%						
Yearly Available Productive Work Hours Per Person:	1,615.00						

Table 1. Initial Capacity Analysis

Column 3 is the calculated total productive hours available from the resource to work on C2 aircraft. This is calculated by multiplying the number of personnel in column 2 with the *Yearly Available Productive Work Hours Per Person.* For example, the last resource in Column 1 *Aircraft Preservation (Mech)* has three personnel and the *Yearly Available Productive Work Hours Per Person* is 1,615 hours thus the *Total Hours Available* is 4,845 (3 x 1,615).

Column 4 lists the WLS hours required by resource to complete one C2 aircraft. The hours are from the C2 WLS provided by C2 production and planning staff. Column 5 lists our calculated Annual C2 Capacity based on the WLS. This is calculated by dividing data in Column 3 with data in Column 4. For example, *Fiberglass* (1,615/56) = 28.184. Fiberglass has a calculated capacity of 28.84 C2s per year.

If the C2 production line were to execute their WLS hours with no added efficiency,

the calculation in Column 5 shows four resources *REPAIR/MOD – SHEETMETAL, DISSY/RPR/MOD/ASSY – MECHANIC, ASI,* and *MRT* to have insufficient hours to complete the six C2s without resorting to overtime or additional hiring. Since the C2 production line produced six C2s last year, this lack of capacity motivated us to look at the C2 production efficiency.

Chase, Jacobs and Aquilano define *efficiency* as a ratio of the actual output of a process relative to some standard or the ratio of the actual output of a process relative to some standard. According to C2 planning staff, the C2 production team historically has been able to complete their work requirements by executing only 89 percent of the WLS, thus their efficiency rate is 1.0/0.89 =1.124. Column 6 lists the historical estimate of hours spent on one C2 by resource based on the C2 production line efficiency rate. Column 6 was calculated by dividing Column 4, (*Work Load Standard (WLS) Hours Required Per C2) by* the *C2 Production Team Efficiency Rate.* For example, *E2/C2 Repair/Mod - Sheetmetal (*3,632/ *1.124) = 3,232.* Column 7 lists the *Calculated Capacity Based on Historical Estimate Per Aircraft Hours.* This is calculated by dividing Column 3 with Column 6. Since the C2 production line is able to execute below their WLS they

effectively increased their capacity. For example, the *MRT* and *ASI* resources were able to increase their capacity from 5.47 and 4.54 C2s per year to 6.2 and 5.1 C2s per year respectively. Nevertheless, C2 production line efficiency alone does not explain how they were able to complete six C2s last year. In order to produce six C2s, the resources would have needed to expend more hours than what was listed available in Column 3. We wanted to know the total hours each of the resources expended based on historical estimate and efficiency (Column 8) to produce six C2s.

Column 8 lists the calculated hours necessary to expend by the C2 resources to produce the six C2s last year based on historical estimates and a 1.124 efficiency rate. Column 8 is calculated by multiplying *Historical Estimate of Hours Spent per Aircraft (Column 6)* with the actual six C2s produced last year. For example, *REPAIR/MOD-SHEETMETAL* (3,332 x 6) = 19,395 hours necessary to expend the resources to produce six C2s. The calculation shows resources *REPAIR/MOD – SHEETMETAL, DISSY/RPR/MOD/ASSY – MECHANIC*, and *ASI* to be significantly higher than the calculated hours available listed in Column 3. The disparity between the available hours, and the hours the three aforementioned resources, motivated us to perform additional analyses. That is, we analyzed the effect of increased demand on the C2 production line found in Chapter V.

B. FUTURE PREDICTIVE ANALYSIS

We can see the model working for six C2s per year. However, we extended our analysis by using a “what if” scenario. What if demand were increased to seven C2s per year? There is no current demand for seven C2s, but no capacity analysis is complete without looking at the effects of increased demand. Analysis in Figure 2 involves using historical estimated C2 production data to predict what capacity will be constrained with the increased demand. For this analysis, we assume 1,615 annual productive work hours per person and 112.4 percent efficiency by the C2 production personnel.

The description of the columns of Table 2 from left to right is as follow:

Column 1 lists the *resources* required to complete the C2 PMI3. The resources were consolidated from the WBS (Figure 6). Column 2 lists the *WLS hours required by resource to complete one C2 aircraft*. The hours for column 2 were provided by C2 production planning staff. Column 3 is the calculated *Total Required Hours Based on WLS,* this is the number of hours required by resources to produce the seven aircraft. This is calculated by multiplying Column 2 with the aircraft production goal (the number of aircraft we plan to produce). For example, *MRT* (590 x 7 = 4,130) resource needs 4,130 hours to produce seven C2s.

Column 4 lists the *Historical Estimated* hours spent on one C2 by resource. This number was calculated by dividing Column 3, *Total Required Hours Based on WLS* with the *C2 Production Team Efficiency Rate,* as defined in the initial analysis above. For example, *MRT (*590 / *1.124) = 525,* showing that even though the WLS calls for 590 hours from the MRT resource, the resource is able to achieve the work by only expending 525 hours.

Column 5 lists the *Total Required Hours Based on Historical Estimate*; this is calculated by multiplying Column 4 with the aircraft production goal of seven aircraft. For example, *REPAIR/MOD – SHEETMETAL (3,232 X 7) = 22,627.* Column 6 lists the *Anticipated Total Hours Available* that is pulled from Column 3 of (Table 1). These available hours are based on the number of personnel in the resource pool and *Yearly Available Productive Work Hours per Person.* If FRC SW hires more personnel or work more overtime these hours would increase.

Column 7 lists the percentage of the *Total Hours Needed For C2 work based on Historical Estimate.* This is calculated by dividing Column 5 by Column 6. For example, *REPAIR/MOD – SHEETMETAL (22,627/9,690) = 233.5 percent.* This tells us that in order to produce the seven C2s in a year, the resource pool needs 233.5 percent of the hours it currently has.

Table 2 Column 7 lists four constrained or bottleneck resource that will prevent the C2 production team from producing seven aircraft, *REPAIR/MOD-SHEETMETAL, DISSY/RPR/MOD/ASSY–MECHANIC, ASI,* and *MRT*. These four resources will require

233.5 percent, 220.8 percent, 137.3 percent, and 113.8 percent of the currently available hours in order to be able to produce the A/C production goal of seven C2s. In addition to these four resources being bottlenecks there may very well be other resources list in Column 7 that will constrain production because they are shared resources thus they cannot give 100 percent of their time to C2. For example, the *Weight and Balance* resource only expend 20 percent of its hours on seven C2 which shows it has the capacity to support the production of 35 C2s. However, this might not be true if the 80 percent of its time are dedicated to production of other FRC SW aircrafts such as the F/A-18's, E-2s, or helicopters. Exactly how much shared resources' capacity are allocated to the C2 production line is beyond the scope of this project. Consideration of the problems encountered with shared resources is an issue for management. One such problem is the variability of demand for resource by other aircrafts. For example, if F18s end up using more of the *Final Paint* resource, and the resource does not have built in flexibility to absorb the added demand, then *Final Paint* resource may become a constraint for the C2 production line.

In summary, this analysis shows that, due to some resource constraints, there is not sufficient capacity without overtime to meet the production demand of six or seven C2 aircrafts. However, we know this is not entirely true, because the C2 production line was able to produce six C2 PMI3 aircraft during FY08 and is expected to do the same FY09. In the following analysis, we will investigate this disparity further to identify how the C2 production line was able to achieve the production of six C2s, given its capacity constraint.

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FUTURE/PREDICTIVE IF GOAL IS TO PRODUCE 7 C2s						
1	2	3	4	5	6	7
RESOURCE	**Work Load Standard (WLS) Hours Require per C2**	**Total Required Hours Based on WLS**	**Historical Estimate per C2**	**Total Required Hours Based Historical Estimate**	**Anticipated Total Hours Available**	**% of Total Hrs Needed for C2 Based on Actual History**
Repair/Mod - Sheetmetal	3,632	25,424	3,232	22,627	9,690	233.51%
Dissy/Rpr/Mod/Assy - Mechanic	6,295	44,065	5,603	39,218	17,765	220.76%
ASI	712	4,984	634	4,436	3,230	137.34%
MRT	590	4,130	525	3,676	3,230	113.81%
Dissy/Rpr/Mod/Assy - Electrician	1,080	7,560	961	6,728	8,075	83.32%
Examination/Evaluation	2,120	14,840	1,887	13,208	19,380	68.15%
Repair/Mod/Misc - Machinist	240	1,680	214	1,495	3,230	46.28%
Final Paint	1,100	7,700	979	6,853	16,150	42.43%
Corrosion Control / PMB / Intakes	1,000	7,000	890	6,230	16,150	38.58%
PAR Team	192	1,344	171	1,196	3,230	37.03%
Upholstery Shop	82	574	73	511	1,615	31.64%
NDI - Bldg.460	64	448	57	399	1,615	24.71%
Aircraft Mechanic (A&T)	56	392	50	349	1,615	21.61%
Fiberglass	56	392	50	349	1,615	21.61%
Work Documentation (Log Clerk)	52	364	46	324	1,615	20.06%
Weight and Balance	80	560	71	498	3,230	15.42%
Ordnance - Fire Bottles / Aircraft	28	196	25	174	1,615	10.77%
Aircraft Preservation (Mech)	58	406	52	361	4,845	7.45%
C2 Production Team Efficiency Rate	**112.40%**					
Yearly Available Productive Work Hours per Person:	**1,615.00**					

Table 2. Future Predictive Analysis

C. ANALYSIS OF CROSSED-TRAINED PERSONNEL

We used this analysis to look at what happens to capacity when a *flexibility workers* approach is used. Flexibility workers have multiple skills and the ability to switch from one kind of task to another (Richard B. Chase, 2006). Based on interviews, C2 management estimates approximate 60 percent of the C2 production personnel are cross trained to perform multiple jobs. This means 60 percent of the total resource hours can be pooled. Based on this assumption we modified our spreadsheet (Table 3) to analyze what would happen if some of the resources could share their excess capacity. In our view, this analysis can help explain why the C2 production line was able to meet their production of six C2s last year, even though previous analysis indicated FRC SW did not have enough resources.

A list of resources we analyzed is shown in Table 3. We omitted some resources from the analysis because their functions are generally specialized or they are shared resources the C2 production line does not control. For example, *Work Documentation (Log Clerk)* would normally not be crossed trained to turn a wrench as a mechanic. Any *Work Documentation (Log Clerk)* excess capacity would normally not be able to be shared with other C2 resources. Other resources such as the *Final Paint* are not directly owned by the C2 Production line, thus they are not used as cross-trained resources in our analysis. Based on Table 2 results, we know 42.4 percent of the *Final Paint* capacity would have to be allocated to C2 in order to produce seven C2s. To produce six C2s, we calculated *Final Paint would* need to allocate 36.4 percent their capacity to the C2.

For this analysis, we assume the following resources are not cross trained due to specialization, or the resource is not directly owned by the C2 production line.

- MRT
- Final Paint
- PAR Team
- Upholstery Shop
- Work Documentation (Log Clerk)
- Weight and Balance (W & B)
- Ordnance - Fire Bottles / Aircraft

1	2	3	4	5	6	7	8	9	10
RESOURCE	**# of Personnel**	**Total Hours Available**	**Crossed Trained Hours Avail for Sharing**	**Historical Estimate Hours Required per C2**	**Required Hours for 6 C2s Per Year**	**Additional Hours Needed**	**Extra Capacity Hours**	**Shareable Hours**	**Non-shareable Excess Capacity**
Repair/Mod - Sheetmetal	6	9,690	5,814	3,232	19,392	9,702			-
Dissy/Rpr/Mod/Assy - Mechanic	11	17,765	10,659	5,603	33,618	15,853			-
ASI	2	3,230	1,938	634	3,804	574			-
Dissy/Rpr/Mod/Assy - Electrician	5	8,075	4,845	961	5,766	-	2,309	2,309	-
Examination & Evaluation	12	19,380	11,628	1,887	11,322	-	8,058	8,058	-
Repair/Mod/Misc - Machinist	2	3,230	1,938	214	1,284	-	1,946	1,938	8
Corrosion Control / PMB / Intakes	10	16,150	9,690	890	5,340	-	10,810	9,690	1,120
NDI - Bldg.460	1	1,615	969	57	342	-	1,273	969	304
Aircraft Mechanic (A&T)	1	1,615	969	50	300	-	1,315	969	346
Fiberglass	1	1,615	969	50	300	-	1,315	969	346
Aircraft Preservation (Mech)	3	4,845	2,907	52	312	-	4,533	2,907	1,626
TOTAL:		**87,210**	**52,326**	**13,630**	**81,780**	**26,129**	**31,559**	**27,809**	**3,750**
C2 Production Team Efficiency Rate	112.4%								
Yearly Available Productive Work Hours Per Person:	1,615.00								

Table 3. Analysis of Cross-Trained Personnel

A description of Table 3 columns are as follow:

Column 1 lists the *resources* required to complete the C2 PMI3. Column 2 lists the number of personnel identified as part of the resource in Column 1 as shown originally in Table 1. Column 3 lists the calculated *total work hours available*. This is calculated by multiplying the *Yearly Available Productive Work Hours Per Person* (i.e., 1,615 hours) with the number of personnel listed for the resource. Since this has been previously calculated, the data for Column 3 was pulled from Table 1 Column 3.

Column 4 lists the *Crossed Trained Hours Available for Sharing* for the resource. Given that 60 percent of the personnel are assumed to be crossed trained, Column 4 can be calculated by multiplying the hours in Column 3 by 0.60. For example, ASI would have (3,230 x 0.60) = 1,938 crossed trained hours to share with other resources. According to FRC SW staff, these cross training does have limitations. The workers may not be totally crossed trained to work in all the resource pools; this limits how they can share their hours. For example, a machinist working on the plane one day is not likely to be an electrician the next day. A more likely scenario would be a sheet metal mechanic working in the back shops one day, and then assisting with aircraft repairs and modifications the next day.

Column 5 lists the *historical estimated hours required* by the resource to complete one C2. This number was calculated by dividing the *Work Load Standard* hours by the *C2 Production Team Efficiency Rate*. For example, for *Fiberglass* resource (56 hours /1.124 efficiency rate) = 50 hours. This has been previously calculated in Table 1 Column 6 as well as in Table 2 Column 4.

Column 6 lists the *required hours to complete six C2 aircraft*. This is calculated by multiplying Column 5 by 6. For example, *REPAIR/MOD - SHEETMETAL* resource (3,232 hours x 6 aircraft) = 19,392 hours. This means that 19,395 hours of the various resources are needed to complete six C2s. Once we determined how many hours are needed, we then calculated how many *additional hours are* needed by the resources. Column 7 lists the shared capacity required by the resource. In other words, the resources with entries in Column 7 do not have enough of its own hours to complete six

C2s. Thus, they need to acquire shared hours elsewhere to meet the capacity requirement. For example, the *REPAIR/MOD – SHEETMETAL* resource needs 19,392 hours but it has only 9,690 hours, so, in order to meet capacity for six C2s, it needs an additional 9,702 shared hours. This can be calculated by subtracting Column 3 from Column 6.

Column 8 lists the *extra capacity hours*. This is calculated from subtracting the *required hours* in Column 6 from the *total available hours* in Column 3. For example, *EXAMINATION & EVALUATION* extra capacity hours is (19,380 hours – 11,322 hours) = 8,058 hours.

Column 9 lists the *shareable hours* for the resource. The hour is the minimum of Column 4 and Column 8. For example the *DISSY/RPR/MOD/ASSY-ELECTRICIAN* resource has 4,845 *crossed trained hours available for sharing* but it only has 2,309 *extra capacity hours*, thus the *sharable hours* is 2,309, the minimum of the two. Once we found the shareable hours we wanted to find out how much of these hours are not shareable.

Column 10 lists the *non-shareable excess capacity* hours, which is a form of idle capacity. This is the difference between Column 8 and Column 9. What is interesting to note here is that even though a resource has the extra capacity hours, it does not necessarily mean it can share the hours. An example of why this happens is to imagine a worker who is done with his or her job but is not cross trained to work on anything else. The worker has some extra hours but since he or she is not cross trained the excess hours is not shareable.

Based on the assumption that 60 percent of the personnel in Table 3 are crossed trained, the sum of Column 9 reveals 27,809 hours available to be shared among the resources. Table 3 Column 7 total shows 26,126 hours are needed in order to complete six C2 PMI3 in a year. Hence, this analysis supports the argument that the FRC SW C2 production line does have the capacity to complete six C2 PMI3 aircraft in a year, given that 60 percent of the C2 production personnel are crossed trained and sharing excess hours. Importantly, all the calculations were made with the C2 production line operating

at 112.4 percent efficiency, which only requires 81,780 hours to complete six C2s. If the C2 production line were to execute their WLS at 100 percent efficiency, they would need approximately (81,780 hours x 1.124) 92,021 hours to complete six C2s. Having only 87,210 hours available, the C2 production team would not be able to complete six C2s without resorting to overtime or additional hiring.

This analysis supports the argument that the C2 production line has the capacity to produce six C2s without resorting to OT. However, the C2 production staff indicated the C2 production line works a significant amount of OT, which may indicate the percentage of, crossed trained personnel may be less than 60 percent. (i.e., not enough crossed trained personnel in the skill set for the constrained resources in Table 3 Column 7 (*REPAIR/MOD-SHEETMETAL, DISSY/RPR/MOD/ASSY-MECHANIC, and ASI))* or the actual efficiency rate may be less than 112.4 percent.

V. CONCLUSION AND RECOMMENDATIONS

This chapter provides an overall conclusion to our research and our recommendations. The results of this project is provided to assist management with their ongoing efforts in providing quality maintenance support while looking for ways to reduce cost and maintain their flexibility to meet fleet demands. Therefore we have included recommendations for future research into the C2 production

A. CONCLUSION AND RECOMMENDATIONS

In this project, we analyzed the current capacity of the C2 production line based on the data provided by FRC SW. Our calculations show that if the C2 production line is able to execute their workload at 112.4 percent efficiency and their maintenance personnel are flexible workers who have multiple skills and qualifications, FRC SW staff is able to execute the current production rate of six C2s per year. However, at the current capacity the C2 production line will not be able to meet an unplanned demand of an additional C2 PMI3 without resorting to more labor through overtime or additional hiring. In Chapter IV, we introduced the “what if” scenario of production demand increase to seven C2s. The demand increase may come in a form of an emergency repair induction due to fleet operational factors. Based on our research, the C2 production line is already experiencing reasonable amount of overtime and weekend work. Management may want to consider increase capacity now and conserve overtime and weekend work to help absorb emergency repairs. What is the likelihood of increased demand? What service level does FRC SW desire to provide the fleet? These are questions beyond the scope of our project but they are important for FRC SWs management to consider.

The answers to the aforementioned questions will determine FRC SW’s approach to capacity management. If high customer service level to the fleet outweighs the cost for additional capacity then perhaps it might be in the best interest for FRC SW to purchase additional capacity and hold it idle until it is required. Additionally, FRC SW management may also consider statistical fluctuation and dependent events in the PMI3 process. A dependent event is when one operation must be completed before a second

operation can begin. The C2 PMI3 has many of these dependent events, for example the fuel cells have to be gas free before work can be done in the fuel cells area. Statistical fluctuations occur because the time required to complete a task varies. When statistical fluctuation is combined with dependent events, the C2 flow across its production line may be slowed. The idea is that when an event takes more than the average amount of time, the dependent events are delayed and may not be able to catch up later. To minimize the effect of these statistical fluctuation and dependent events FRC SW may want to, again, increase its capacity cushion by purchasing capacity now and reduce overtime usage. Overtime would be used to absorb unexpected demand and process time variations.

1. Continue to Find Reduction of Cycle Time

The current *E2/C2 New Current State Value Stream Map* shows the C2 production line personnel is continuously looking for ways to improve processes to improve quality and reduce cycle time.

- Pre-induction phase personnel are looking for ways to improve meeting the move schedule.
- Pre-Disassembly personnel are looking for ways to improve paperwork processing.
- MRT/Test line personnel are training on protection of C2 flight control surfaces and review part storage process.

The following example illustrates how cycle time reduction can have an impact on the fleet.

Suppose that the U.S. Navy has 40 C2 aircraft, each of which costs the taxpayers $40 million, and has a Mean Time Between Maintenance (MTBM) Periodic Maintenance Interval (PMI) performed every four years. If the Maintenance Down Time (MDT) is one year, a C2's readiness can be calculated with the formula commonly expressed as operational availability: Ao=MTBM/(MTBM+MDT). Based on the formula, we can improve readiness by increasing the MTBM or decreasing the MDT. For our C2

example, Ao will be 4 years/(4 years +1 year) = 0.8. Thus, only 80 percent of 40, or 32, aircraft will be mission-capable on average since an aircraft would be available for mission for four years (and at FRC SW for one year) out of every five years. This also means eight aircraft will be non-mission capable at any given time. If the MDT can be reduced to six months, Ao will be 0.889 (4 years/(4years+.5 year)), or an average of only 4.44 C2 Greyhounds instead of 8 will be at FRC SW for maintenance at any given time. It is equivalent to having 3.56 additional C2 Greyhounds (worth more than $142.4m) in the fleet. On the other hand, if having 32 mission-capable aircraft available is adequate, it could mean reducing the fleet size by four aircraft.

B. FUTURE RESEARCH

This project focused on the analysis of the capacity of the C2 PMI3. We propose a recommendation for follow studies to include analysis of the financial aspect of the business, specifically the cost-benefit of adding additional capacity while reducing weekend and overtime hours. Reducing the regular use of overtime means FRC SW can save overtime and weekends for demand variability and increases.

Additionally, if major adjustments to process or capacity are contemplated by management, we recommend management consider investment into modeling and simulation studies. With modeling and simulation, management may be able to obtain data to help make more informed capacity decisions.

C. PROJECT LIMITATIONS

Ideally, we wanted to obtain the resource allocation to the C2 aircraft for any shared resources but due to time constraints, we were unable to obtain the data for this project. Time also constrained our opportunity to conduct more than a limited set of formal interviews.

Our scope also posed a limitation on our project. Our project shows only a fraction of the C2 Production Line. The C2 production line is grander and more complex. To fully grasp the overall picture, our project would have required more time and a greater access to FRC SW resources.

Capability does not address parts or equipment availability. We looked at capabilities mainly focused on work hours and resource pools. FRC SW staff commented that capacity constraints may be affected by delayed parts and equipments — for example, functional Main Landing Gears (MLG). Parts delays may cause reduced capacity because the aircraft must stay in the single flow process longer, preventing work on subsequent aircraft.

LIST OF REFERENCES

Chase, R. B. (2006). *Operations Management for Competitive Advantage (11th edition).* New York: McGraw-Hill/Irwin.

Deputy Under Secretary of Defense. (2007). *Depot Maintenance Capacity and Utilization Measurement Handbook.*

Enterprise, Naval Aviation. (2008, March 01). *A Warfigting Partnership*. Retrieved April 26, 2009, from CNAF: http://www.cnaf.navy.mil/nae/main.asp?ItemID=13

FRC SW SOP. (2009). *E2/C2 Product Line Quality Management System - Standard Operating Procedure (SOP) Number 1*.

FRC SW, Command Overview. (2008). Command Overview. *Fleet Readiness Center Southwest Command Brief* (p. 34). San Diego: Commander, Fleet Readiness Center Southwest.

Goldratt, E. M. (1992). *The Goal: A process of Ongoing Improvement.* Great Barrington: The North River Press.

Island, Naval Air Station North. (2009). *E2/C2 Product Line (Quality Management System).* San Diego: Commander, Air Naval Station North Island.

Kang, K. &. (2006). *Lean Six Sigma for Reduced Cycle Costs and Improved Readiness.* Monterey: Acquisition Research Program, Naval Postgraduate School.

Klammer, T. (196). *Capacity Measurement & Improvement.* Chicago, London, Singapore: IRWIN Professional Publishing.

Markle, J. (2009, February 14). *FRCSW Fares Well in World-Class Competition.* Retrieved April 26, 2009, from Fleet Readiness Center Southwest: http://www.navair.navy.mil/frcsw/news.html#miramar23

Markle, J. (2009, April 01). *FRCSW Site MCAS Miramar: Ready to Repair on a Moment's Notice.* Retrieved March 09, 2009, from Fleet Readiness Center Southwest: http://www.navair.navy.mil/frcsw/news.html#miramar23

McNair, C. V. (1998). *Total Capacity Management (Optimizing at the Operational, Tactical, and Strategic Levels).* Boca Raton, Boston, London, New York, Washington D.C.: ST. Lucie Press.

NAVAIR. (2009, April 09). *Fleet Readiness Center Southwest*. Retrieved January, February, March, April, May 1-30, 2009, from NAVAIR: http://www.navair.navy.mil/frcsw/

NAVAIR PMI3. (2006). *Planned Maintenance Interval (PMI) C2A, Bureau Number 162140 through 162178.* Naval Air Systems Command.

NAVY. (2009). Retrieved from http://www.navy.mil/navydata/fact_display.asp?cid=1100&tid=100&ct=1

Womack, J. P., & Jones, D. T. (1996). *Lean Thinking: Banish Waste and Create Wealth In Your Corporation.* New York: Simon & Schuster.

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